

# METHODS OF FORMING HONEYCOMB SANDWICH COMPOSITE PANELS

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention:

The present invention relates to lightweight high-stiffness composite panels used in aircraft, motor vehicles, vessels, buildings, or general industrial equipment. More particularly, it is concerned with methods of forming composite panels having a honeycomb sandwich structure by using an RTM (Resin Transfer Molding) process.

### 2. Description of the Related Art:

Previously known methods of forming honeycomb sandwich panels include a molding method in which outside plates previously formed as skins are placed on top and bottom surfaces of a honeycomb core with an adhesive applied between them and the outside plates and the honeycomb core are bonded together under heat and pressure, as well as a molding method in which prepreg sheets and a honeycomb core are stacked by hand lay-up operation with an adhesive applied between them, the prepreg sheets and honeycomb core thus stacked are covered with a vacuum bag, an internal space of the vacuum bag is drawn by vacuum, and then the stack is subjected to heat and pressure by using a hot press or an autoclave.

In addition, Japanese Patent Laid-Open No. 295362/1997 describes a method of forming a honeycomb sandwich panel by

the RTM process, in which an impregnating resin is kept from flowing into a honeycomb core by use of a resin/moisture barrier film formed of a particular macromolecular film.

Since the aforementioned method of forming honeycomb sandwich panels utilizes prepreg as a raw material, it requires high material cost and expensive facilities for the storage of materials and for a curing operation. Further, this method involves many processing steps, and this would develop a problem of cost reduction of composite materials.

In the aforementioned RTM process for forming a honeycomb sandwich panel by use of a particular macromolecular film, it is necessary to apply an adhesive to both sides of the macromolecular film because outside plates and a honeycomb core are bonded with the macromolecular film (thermoplastic resin) placed between them. As a method of forming alternative panels for existing sandwich panels, the RTM process would pose new problems, such as an increase in weight due to the use of additional material.

Furthermore, when a panel of a complex shape having a steplike portion or a curved surface, for instance, is formed by the aforementioned method of forming the honeycomb sandwich panel that uses the macromolecular film, it is difficult for a finished panel to keep its shape and the desired shape will not easily be obtained due to poor adhesion and low flexibility of the macromolecular film. Moreover, sealing performance

against resin would become insufficient and the stiffness of the finished panel would deteriorate.

#### SUMMARY OF THE INVENTION

The present invention has been made in view of the aforementioned problems. Accordingly, it is an object of the invention to provide a method of forming honeycomb sandwich composite panels in which a honeycomb core is sealed in a mold prior to resin impregnation to prevent the resin from flowing into cells of the honeycomb core during resin impregnating operation in order that the RTM technique adopted in molding solid materials (plate materials), for instance, can be used.

According to a method of forming a honeycomb sandwich composite panel, a dry fabric is stacked on both sides of a honeycomb core with a thermosetting sealing material having an adhesive property placed in between, and the sealing material and the dry fabric are heated at the curing temperature of the sealing material to cause initial hardening of the sealing material and to dry the dry fabric. Subsequently, the dry fabric is impregnated with a thermosetting resin and the resin impregnated into the dry fabric is hardened by hot-pressing an entire assembly thus prepared under specific conditions. According to this method, it is possible to perform operations from the sealing of the honeycomb core with the sealing material to its hardening in one step, prevent the

resin from flowing into cells of the honeycomb core during resin impregnating operation, and thereby produce low-cost honeycomb sandwich components.

According to another method of forming a honeycomb sandwich composite panel, a dry fabric is stacked on both sides of a honeycomb core with a thermosetting sealing material having an adhesive property placed in between, and the sealing material is hardened by heating the sealing material and the dry fabric to the curing temperature of the sealing material and maintaining this temperature for a specified period of time. Subsequently, the dry fabric is impregnated with a thermosetting resin while varying the temperature of the sealing material and the dry fabric to a resin impregnating temperature and maintaining this temperature for a specified period of time, and the resin impregnated into the dry fabric is hardened by heating the sealing material and the dry fabric to the curing temperature of the thermosetting resin and hot-pressing them for a specified period of time. According to this method, it is possible to prevent the resin from flowing into cells of the honeycomb core during resin impregnating operation and mold low-cost honeycomb sandwich components by using the RTM technique which is adopted in molding solid materials, for instance.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram showing a lamination process according to a method of forming a honeycomb sandwich composite panel of the invention;

FIG. 2 is a diagram showing a molding procedure according to the method of forming the honeycomb sandwich composite panel of the invention;

FIG. 3 is a diagram showing an example of a sealing member for use in the honeycomb sandwich composite panel of FIG. 1;

FIG. 4 is a diagram showing another example of a sealing member for use in the honeycomb sandwich composite panel of FIG. 1;

FIG. 5 is a diagram showing still another example of a sealing member for use in the honeycomb sandwich composite panel of FIG. 1;

FIG. 6 is a diagram showing yet another example of a sealing member for use in the honeycomb sandwich composite panel of FIG. 1; and

FIG. 7 is a diagram showing a molding procedure according to a method of forming a honeycomb sandwich composite panel in another embodiment of the invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the invention are described below with reference to the drawings.

FIG. 1 shows laminating materials and a lamination method used in a method of forming a honeycomb sandwich composite panel according to the invention. The honeycomb sandwich composite panel 1 is formed of a honeycomb core 2, sealing members 3 placed on both sides of the honeycomb core 2, and a plurality of dry fabric sheets 4 placed on top of the individual sealing members 3. These dry fabric sheets 4 are impregnated with a resin. The honeycomb core 2 and the dry fabric sheets 4 have the same structures that have conventionally been used in this kind of honeycomb sandwich composite panel.

It is preferable that the sealing members 3 have the ability to harden in a temperature range lower than recommended curing temperature as well as heat resistance to withstand high temperatures falling within a temperature range in which the impregnating resin is cured from the viewpoint of efficiency in manufacturing the honeycomb sandwich composite panel 1. It is also preferable that the sealing members 3 have a sufficient sealing effect to prevent the resin from flowing into the honeycomb core during resin impregnation and that adhesion between the honeycomb core and outside sheets be strong enough and the sealing members 3 be of a kind of material which would not become a dissimilar material when they are joined into a single structure. Further, when the impregnating resin is a thermosetting resin, the sealing members 3 should preferably

include a thermosetting epoxy resin capable of curing at a temperature between 120°C and 180°C.

Specific structures of the sealing members 3 are shown in FIGS. 3 to 6.

The sealing member 3 shown in FIG. 3 has a three-layered structure of thermosetting resin films 3a whose viscosity is increased by adding glass microballoons to an epoxy resin material, in which the viscosity of the resin can be adjusted by the amount of the glass microballoons added. Alternatively, short fibers or non-woven fabric of glass may be used instead of the glass microballoons.

The sealing member 3 shown in FIG. 4 is produced by sandwiching a carrier material 3b which is used as an adhesive film between epoxy resin adhesive films 3c. Passage of the resin is impeded by the size of openings formed between fibers, and this makes it possible to control sagging and flow-out of the resin into the honeycomb core.

The sealing member 3 shown in FIG. 5 has a three-layered structure carrying thermosetting adhesive properties, in which an epoxy resin film 3a is sandwiched between epoxy resin adhesive films 3c.

The sealing member 3 shown in FIG. 6 is formed of three epoxy resin adhesive films 3c. This sealing membrane can be formed while preventing a decrease in viscosity by controlling temperature increase.

Next, an example of a method of forming the honeycomb sandwich composite panel of this invention is described.

First, dry fabric sheets 4 and a honeycomb core 2 are prepared and dry fabric sheets 4 are stacked on both sides of the honeycomb core 2 with sealing members 3 placed between them as shown in FIG. 1 to form a honeycomb sandwich assembly.

Then, the honeycomb sandwich assembly is set in a molding jig which is not illustrated. A resin impregnating line is connected to the molding jig by ordinary means. The mold containing the honeycomb sandwich assembly is placed inside a hot press or a furnace by an ordinary method, where preparatory steps for molding operation are finished.

Subsequently, heated by the hot press or furnace, the temperature within the internal space of the molding jig is increased up to  $120 \pm 5^\circ\text{C}$  at a rate of  $1^\circ\text{C}$  per minute or less and the temperature of  $120 \pm 5^\circ\text{C}$  is maintained for a period of  $130 \pm 10$  minutes and, then, the temperature is increased from  $120 \pm 5^\circ\text{C}$  up to  $160 \pm 5^\circ\text{C}$  at a rate of  $1^\circ\text{C}$  per minute or less, as shown in FIG. 2. Here, the degree of vacuum within the molding jig should preferably be such that its internal space is held at a pressure of  $-600$  mm Hg or less (where the atmospheric pressure is assumed to be  $0$  mm Hg) after 120 minutes have passed since the temperature reached  $120^\circ\text{C}$ . The dry fabric sheets 4 are dried and the honeycomb core 2 is sealed as a result of initial hardening of the sealing members 3 in the above sequence



of processing steps. Since the initial hardening of the sealing members 3 and drying operation of the dry fabric sheets 4 are performed simultaneously, it is not necessary to add any new processing step to the ordinary sequence of processing steps for molding solid panels.

When the temperature inside the molding jig has reached  $160 \pm 5^\circ\text{C}$ , a thermosetting epoxy resin is injected into the molding jig through the impregnating line and the dry fabric sheets 4 are impregnated with the thermosetting resin with the injection pressure held between 2 and 3 atmospheric pressures.

When impregnation of the dry fabric sheets 4 with the thermosetting resin has finished, the temperature inside the molding jig is further increased from  $160 \pm 5^\circ\text{C}$  to  $180^\circ\text{C}$ . The thermosetting resin impregnated into the dry fabric sheets 4 is hardened by heat at a curing temperature of  $180^\circ\text{C}$  and a pressure equal to or greater than resin impregnating pressure, whereby the honeycomb sandwich composite panel is molded.

Although the thermosetting epoxy resin (curing temperature:  $180^\circ\text{C}$ ) is used as the impregnating resin and the epoxy resin film or epoxy adhesive film capable of curing at  $180^\circ\text{C}$  is used as the sealing member 3 in the foregoing embodiment, it has been verified experimentally that sufficient sealing performance and the degree of cure are obtained even when the sealing member 3 is hardened by heat at  $120^\circ\text{C}$  for 60 minutes.

The curing temperature of the sealing member 3 is lower than the temperature at which the impregnating resin is impregnated in the aforementioned embodiment. In a case where the former is higher than the latter, initial hardening of adhesive is performed by increasing the temperature of the sealing member 3 up to an adhesive curing temperature and, then, the temperature is lowered down to the resin impregnating temperature so that the dry fabric sheets 4 are impregnated with the resin.

It is to be pointed out that vacuum pressure is not used in an early stage of heating operation for hardening the sealing member 3, but its hardening is performed at  $121 \pm 5^{\circ}\text{C}$  and the vacuum pressure is used after 120 minutes have elapsed from the beginning of the heating operation.

In a case where the sealing member 3 is an adhesive having a narrow curing temperature range, the temperature of the sealing member 3 is increased up to the curing temperature, and an impregnating process is started upon completion of hardening the sealing member 3. In this case, good sealing performance is obtained if the sealing member 3 is a film which hardens at  $180^{\circ}\text{C}$ , because its heat resistance is sufficiently high. Even when the resin impregnating temperature and resin curing temperatures in succeeding resin impregnating and curing processes are equal to or higher than  $120^{\circ}\text{C}$ , the sealing member 3 is post-cured at that temperature (resin impregnating

temperature or resin curing temperature) so that the sealing member 3 can prevent the resin from flowing into the honeycomb core 2.

Further, since the combination of materials of the honeycomb sandwich composite panel using the sealing members 3 is similar to that of a sandwich panel produced by the hand lay-up operation, the sealing members 3 would not become a dissimilar material with respect to the honeycomb sandwich panel, unlike the moisture barrier film described in Japanese Patent Laid-Open No. 295362/1997.

Experimental results of a flatwise tensile test of the honeycomb sandwich composite panel of the invention are shown in the following table.

Table 1

| Results of flatwise tensile test     |  |  |
|--------------------------------------|--|--|
| Flatwise tensile strength            | (1) 0.226 kgf/mm <sup>2</sup><br>(2) 0.222 kgf/mm <sup>2</sup><br>(3) 0.212 kgf/mm <sup>2</sup><br>(4) 0.223 kgf/mm <sup>2</sup>   | State of fracture: All cores broke down. |
| Sealing efficiency                   | 95-99% (when resin is present in honeycomb core after impregnation)  |  |
| Sealing member                       | Epoxy resin film thermosetting between 120°C and 180°C (AF325(M) manufactured by Minnesota Mining Manufacture Company) is sandwiched between adhesive films thermosetting at 180°C (MB1515-3M manufactured by Sci-Tech Corp.). |  |
| Honeycomb core                       | Nomex-GR. 3.0, thickness 1.0" (E.I. Dupont Company)  |  |
| Impregnating resin                   | Epicoat 6003 (Yuka Shell Company)  |  |
| Dry fabric                           | Carbon fibers (MIL Standard 3k-70-PW)  |  |
| Curing temperature of sealing member | 120°C (120 minutes)  |  |
| Resin impregnating temperature       | 40°C   |  |
| Panel hardening temperature          | 180°C  |  |

It has been verified by the flatwise tensile test that the honeycomb sandwich composite panel has no problem with respect to its strength.

Although the flatwise tensile of the sealing member has not been ascertained since the tensile test was conducted for the honeycomb core, a sufficient adhesive strength is obtained because components of common honeycomb structures employ materials equivalent to those used in the aforementioned test.

FIG. 7 shows a method of forming a honeycomb sandwich composite panel according to another embodiment of this invention.

In the embodiment shown in FIG. 7, a thermosetting epoxy resin adjusted to a low viscosity is used as an impregnating resin and, in a manner similar to the embodiment shown in FIG. 2, dry fabric sheets 4, sealing members 3 and a honeycomb core 2 are prepared and a honeycomb sandwich assembly is formed by stacking the dry fabric sheets 4 on both sides of the honeycomb core 2 with the sealing members 3 placed between them. The honeycomb sandwich assembly is set in a molding jig and a resin impregnating line is connected to the molding jig. The mold containing the honeycomb sandwich assembly is placed inside a hot press or a furnace, where preparatory steps for molding operation are finished.



Subsequently, heated by the hot press or furnace, the temperature within the internal space of the molding jig is increased up to  $120 \pm 5^\circ\text{C}$  at a rate of  $1^\circ\text{C}$  per minute or less and the temperature of  $120 \pm 5^\circ\text{C}$  is maintained for a period of  $130 \pm 10$  minutes and, then, the temperature is lowered from  $120 \pm 5^\circ\text{C}$  to  $40 \pm 5^\circ\text{C}$  at a rate of  $1^\circ\text{C}$  per minute or less. Here, the degree of vacuum within the molding jig should preferably be such that its internal space is held at a pressure of - 600 mm Hg or less (where the atmospheric pressure is assumed to be 0 mm Hg) after 120 minutes have passed since the temperature reached  $120^\circ\text{C}$ . The dry fabric sheets 4 are dried and the honeycomb core 2 is sealed as a result of initial hardening of the sealing members 3 in the above sequence of

processing steps. Since the initial hardening of the sealing members 3 and drying operation of the dry fabric sheets 4 are performed simultaneously, it is not necessary to add any new processing step to the ordinary sequence of processing steps for molding solid panels.

When the temperature inside the molding jig has reached  $40\pm 5^{\circ}\text{C}$ , a thermosetting resin is injected into the molding jig through the impregnating line and the dry fabric sheets 4 are impregnated with the thermosetting resin with the injection pressure held between 2 and 3 atmospheric pressures.

When impregnation of the dry fabric sheets 4 with the thermosetting resin has finished, the temperature inside the molding jig is increased from  $40\pm 5^{\circ}\text{C}$  to  $180\pm 5^{\circ}\text{C}$ . The thermosetting resin impregnated into the dry fabric sheets 4 is hardened by heat at a curing temperature of  $180^{\circ}\text{C}$  and a pressure equal to or greater than resin impregnating pressure, whereby the honeycomb sandwich composite panel is molded.

Although the temperature at which the thermosetting resin is impregnated is maintained at a constant temperature for a specified period in the aforementioned embodiment, it is possible to eliminate the need for maintaining a constant resin impregnating temperature for a specified period by further reducing the rate of temperature increase.



Furthermore, it is possible to use a single-layered sealing member 3 by reducing the mesh size of its carrier material.

As thus far described, it becomes possible to one-piece mold a honeycomb sandwich composite structure by the RTM technique and produce low-cost honeycomb sandwich components since initial hardening of sealing members for sealing a honeycomb core and drying operation of dry fabric sheets are carried out simultaneously according to this invention.

While the presently preferred embodiments of the present invention have been shown and described, it is to be understood that the disclosure is for the purpose of illustration and that various changes and modifications may be made without departing from the scope of the invention as set forth in the appended claims.